

CHAPTER 2 Transportation Risk - Concepts and Overview

A number of terms used throughout this User Guide have specific meanings in the fields of radiological risk analysis and RAM transportation. The most important of these, along with terms for underlying concepts of radioactivity and risk, are defined and explained in this chapter. A full Glossary of Terms may be found in Appendix A.

2.1 Risk and Risk Assessment

Risk is commonly defined as the product of a consequence and its probability of occurrence. What this means in the context of RADTRAN 5 is that transportation risks, like the risks associated with any complex process, may be decomposed into “what can happen...how likely things are to happen, and the consequences for each set [of things that can happen]” (Helton, 1991). As the terminology in this definition implies, set theory provides an ideal framework for formal expressions of risk.

For accident risk assessment, the answer to the first question (“What can happen?”) is that the set of all accidents can be expressed as disjoint sets of accidents (S_i , $i=1,...,nS$). In other words, sets of accidents such that

- (1) no two sets contain any accidents in common (i.e., are disjoint),
- (2) each set consists of accidents with similar outcomes, and
- (3) the sets are jointly exhaustive (that is, all the sets taken together include the entire range of accidents from low consequence to high consequence).

“How likely things are to happen” can be defined as the probability that an accident in set S_i will take place. The “consequences for each set” consist of one or more specified consequence results (population dose, early morbidity, etc.) (Helton, 1991).

In accident risk analysis with RADTRAN 5, the set of all accidents for the mode(s) being analyzed must be divided by the user into subsets (i.e., into the subsets S_i , $i=1,...,nS$) as described above. The subsets also must satisfy the other conditions described in the previous paragraph. ➤ ***The term “similar outcomes” refers to similar package damage and not to any other features such as driver mortality or time of day.*** The subsets and their probabilities are most commonly developed by means of event-tree analysis, but are not required to be. In RADTRAN, these subsets are referred to as ***accident-severity categories***.

Corresponding probabilities are obtained from the products of accident rate and ***severity fraction*** values. ➤ ***Severity fraction is defined as the conditional probability, given that an accident occurs, that it will be of a specified severity (i.e., belong to a given accident subset).*** There are several legitimate ways of defining sets of occurrences for an analysis. However, the use of anecdotal accounts or other non-quantitative information is not among them. Examples of accident-severity category development include the work of Wilmot (1981), Fischer et al. (1987), and Sprung et al. (1998).

RADTRAN calculates distinct probability-consequence products for up to six exposure pathways for each accident-severity category for all route segments. These products are summed and printed in the main output file. The individual probabilities, consequences, and products are also saved and written to supplementary output files (R5INTERM.DAT, R5PLOT0.DAT, R5PLOT1.DAT, and R5PLOT2.DAT), as discussed in Appendix B.

2.2 Terms used in Radioactive-Material Transportation

2.2.1 Package and Packaging

The terms “package” and “packaging” are formally defined in Volume 10 of the Code of Federal Regulations (CFR), Title 71.4 (10 CFR 71.4). Briefly, in radioactive-material transportation, a **package** consists of a **packaging** and its **radioactive contents**. A **packaging** consists of one or more receptacles and wrappers and their contents, excluding radioactive materials but including absorbent material, spacing structures, thermal insulation, radiation shielding, devices for cooling and absorbing mechanical shock, external fittings, neutron moderators, nonfissile neutron absorbers, and other supplementary equipment. The **radioactive contents** may consist of one or more radioactive materials, which are defined in the next section.

2.2.2 Radioactive Materials, Physical-Chemical Forms, Isotopes, and Radionuclides

The **radioactive contents** of a package are defined by regulation as **radioactive material** (10 CFR 71.4), which is often abbreviated RAM. A radioactive material must contain at least one **radionuclide**. A **radionuclide** is one of two or more atomic forms of an element with the same number of protons, but different numbers of neutrons, in their nuclei. The term **radionuclide** refers only to **unstable** nuclides that emit ionizing radiation. In practice, the term “isotope,” used alone, is generally taken to mean a radionuclide; a non-radioactive nuclide, however, is generally distinguished by the term “stable nuclide” or “stable isotope.”

The description of a radioactive material (package contents) in a RADTRAN 5 analysis must include a user-assigned name, also referred to as a **package identifier**. Each material has one or more **physical-chemical forms**, which are assigned via the constituent isotopes. **Physical-chemical form** is a function of

- (1) physical properties [i.e., whether the material is a monolithic solid, divided solid (powders of various types), liquid, or gas] and
- (2) chemical properties (such as melting point or oxidation state) that might affect dispersion or toxicity in potential accidents.

RADTRAN 5 permits the user to identify one or more physical-chemical forms for each material. Each such form is known as a **physical-chemical group**, and each must be assigned

BOX 2-1

PACKAGE IDENTIFIERS, PHYSICAL-CHEMICAL GROUPS, AND NUCLIDES

Examples of Package Identifiers (Material Names) (user assigned):

UO2 POWDR for Uranium Dioxide Powder
VHLW for Vitrified High-Level Waste
MOLYGEN for Molybdenum-99 Generator

Examples of Physical-Chemical Group Identifiers (user assigned):

VOLSOL for volatile solids (e.g., radoruthenium)
GAS for gaseous materials such as tritium gas
POWDR1 for a metal oxide such as uranium dioxide with a 1-mm average particle diameter

Examples of Radionuclides and their RADTRAN 5 Identifiers (fixed; user cannot vary)

Uranium-235; identifier is U235
Cesium-137; identifier is CS137
Molybdenum-99; identifier is MO99

a **physical-chemical-group identifier** as shown in Box 2-1. Each radionuclide in a material must be assigned to at least one group. Properties such as deposition velocity, which depend on physical state (particle size in the case of deposition velocity), are assigned to the physical-

chemical group. Photon energy, on the other hand, is a property of atoms and so is assigned to individual nuclides. Physical-chemical properties of materials cannot be supplied in advance by RADTRAN. Most radionuclide properties, however, are supplied in the internal library of radionuclide data (see Chapter 3). The notable exception to this is, of course, the radionuclide inventory, i.e., the amount of each radionuclide that is present in the package. Nuclide identifiers, when entered in the format recognized by the RADTRAN 5 internal library (see box for examples), will cause all recorded nuclide properties to be automatically entered in the input file (Appendix D contains a full list of radionuclide identifiers).

2.2.3 Shipment and Related Terms

Shipment, Conveyance, Vehicle, Vessel

A **shipment** is defined as the set of all packages in one or more conveyances, traveling together as a unit. A **conveyance** is any **vehicle**, **vessel**, railcar, or aircraft used to transport packages. Although the term **vehicle** generally refers to trucks, vans, etc. for highway-mode transportation, the terms **vehicle** and **conveyance** are often used interchangeably. The term **vessel** refers only to ships and barges for waterway-mode transportation. More than one package of radioactive material may be transported together in a single conveyance. In the rail mode, more than one conveyance may be transported at the same time in a single shipment (i.e., several railcars in a single train).

Transportation Mode and Keyword VEHICLE

Commercial transportation involves one or more of the five basic modes: highway, railway, waterway, passenger air, and cargo air. Five variants of highway and two variants of waterway mode have been included in RADTRAN 5 for user convenience. The modes and variants available in RADTRAN 5 are listed in Table 2-1, which also indicates the conveyance types most likely to be used with each mode or variant. The old designators used in previous releases of RADTRAN are included for the convenience of long-time RADTRAN users. Each of the transportation modes and variants available in RADTRAN 5 is assigned a numerical mode-identifier (Table 2-1). Potential operational differences within the rail mode (e.g., the differences between general rail freight and dedicated rail) are addressed with user-assigned variable values discussed elsewhere in this User Guide.

The RADTRAN keyword VEHICLE (keywords are discussed in Chapter 3) identifies the field in which the user enters the name assigned to a conveyance type. The user must create an alphanumeric identifier for each conveyance type in a RADTRAN analysis (e.g., SEMI-TRUCK for a tractor-trailer and DELIVERY for a van) and assign each conveyance type to a mode (see Table 2-1). The user also must enter information associated with the conveyance, such as number of crewmembers. Up to 12 distinct conveyance types may be described in a single RADTRAN 5 run. Each conveyance must be assigned to at least one mode, but assignment variations are permitted since more than one conveyance or mode may be used to get a single package or a shipment to its final destination. When more than one mode is used, the one in which the majority of the transportation occurs is referred to as the **primary mode**, while others are referred to as **secondary modes**. A secondary mode is required when material must be moved to its primary-mode conveyance (e.g., an airplane) from its origin point or from the primary mode to its final destination by another vehicle, usually a truck or van.

Table 2-1. RADTRAN 5 Modes and Common Conveyance Types

Mode	Mode Number	Conveyance Types Associated with Mode	Old Name (RADTRAN 4)
HIGHWAY	1	Any truck; usually a tractor-trailer(also called a “semi” or a combination truck)	TRUCK
RAILWAY	2	One or more railcars in a single train	RAIL
WATERWAY_A	3	Any vessel; usually barge	BARGE
WATERWAY_B	4	Any vessel; usually ocean-going ship (>3000 gross tons)	SHIP
CARGO_AIR	5	Any plane carrying only cargo	CARGO_AIR
PASNGR_AIR	6	Any plane carrying passengers & cargo	PASS_AIR
HIGHWAY_A	7	Any truck; usually small truck or passenger van	P_VAN
HIGHWAY_B	8	Any truck; usually cargo van/delivery truck as secondary vehicle with tractor-trailer as primary mode	CVAN_T
HIGHWAY_C	9	Any truck, usually cargo van/delivery truck as secondary vehicle with rail as primary mode	CVAN_R
HIGHWAY_D	10	Any truck; usually cargo van/delivery truck as secondary vehicle with cargo air as primary mode	CVAN-CA

2.3 Terms Associated with Stops and Handlings

The term **stop** refers to any of the various events that may occur in the course of transportation during which a conveyance remains stationary. Most stops are analyzed under keyword STOP. A **handling** is a special type of stop that is treated separately in RADTRAN 5 under keyword HANDLING. In all stops, the shipment is modeled as a stationary point- or line-source; the duration of the stop and the number and average distance (or population density) of persons in the vicinity of a stop are problem-specific input parameters. The RADTRAN 5 stop model is highly flexible and can be used to describe most transportation-related stops with little difficulty. Common types of stops modeled under keyword STOP are listed in Box 2-2 and described briefly below:

Box 2-2 - Common Types of Stops

- Rest/Refueling (Highway mode)
- Classification (Rail mode)
- Port Call (Water modes)
- Intermodal Transfer
- Storage (any mode)

- **Rest/Refueling Stops (HIGHWAY Mode).** For commercial truck shipments, most stop time is incurred at commercial truck stops. Data for this type of stop have been published (Griego et al., 1996; Madsen and Wilmot, 1983). In the case of delivery vans, especially when used as a secondary mode, the stop time is incurred primarily at traffic stops and at intermediate destinations (when packages are delivered to two or more destinations by the same conveyance).
- **Classification Stops (RAILWAY Mode).** The majority of stop time for trains is incurred at classification yards, which may be thought of as nodes along the rail network where trains are broken down and reassembled into new trains according to their ultimate destination on the network. Railcars are inspected at classification stops, and rail inspectors may be exposed as a result. Other personnel in the rail yard also would come within various distances of cars carrying radioactive material while performing their duties. Ostmeyer (1986) describes this type of stop, and all rail worker doses are automatically calculated in RADTRAN 5 according to Ostmeyer's model. However, the stop model may be used to assess the area surrounding the classification yard.
- **Port Calls (WATERWAY Modes).** Most stop time in maritime modes is incurred in ports either at the dock or in an anchorage. Inspectors from the U.S. Coast Guard, the port authority, and possibly the carrier or shipper, may incur exposure during inspection of packages in the cargo areas. Transportation by ship or barge is nearly always a primary mode used in conjunction with a secondary surface mode. Therefore, exposures incurred during or after loading and offloading a ship or barge fall under the heading of intermodal transfers, which are discussed below.
- **Intermodal Transfers.** Packages may be carried part of the way by one mode, removed from the first conveyance, placed in another, and transported all or part of the remaining distance by a second mode. ➔ ***Each change from one mode to another is defined as an intermodal transfer.*** One or more intermodal transfers may be required to get a package from its origin point to its final destination. For example, carriage of a package by vessel (ship or barge) is usually preceded by carriage by truck or rail from the package's origin point to a marine port, where the package is loaded onto a vessel (1st intermodal transfer). At the final port of call, the package is usually offloaded to a truck or railcar that carries the package to its final destination (2nd intermodal transfer). Doses to port workers (except handlers) incurred during an intermodal transfer can be calculated with the RADTRAN STOP model (Neuhauser and Weiner, 1992a:b)
- **Storage.** Temporary storage may be associated with intermodal transfer. Warehouse employees and other workers may be exposed during storage. Storage is modeled in the same manner as an ordinary stop with appropriate input values, as described by Neuhauser and Weiner (1992a).

2.3.1 Two Options in Stop Model

A stop can be modeled in two ways as described in Box 2-3. Either radius values and population densities **or** distances and numbers of persons are assigned by the user. RADTRAN 5 allows the user to separately label each stop, although stops also can be treated in an aggregate manner. In the latter case, for example, all fuel stops might be treated as a single stop equal in duration to the sum of the durations of individual stops, with average or bounding values for other parameters.

Box 2-3. Two Ways to Estimate Potentially Exposed Population at a Stop

- 1. Population Density within annular area(s) – User specifies population density and two or more radial distances**
- 2. Number of Persons at an average radial distance – User specifies number of persons and one radial distance**

2.3.2 Separate Model for Handling and Inspection

Handlings and inspections are special types of stop-related activities that are treated separately under keyword HANDLING. Handlers and inspectors are routinely located closer to a package or shipment for longer periods of time than most other persons at stops. Thus, they constitute special subgroups of potentially exposed persons for whom dose estimates may be separately calculated (Weiner and Neuhauser, 1992a,b). A line-source method of calculating handling dose is used for all but the smallest packages. Doses for handling the latter are calculated with an empirical factor. As noted in the section on stops, intermodal transfers have characteristics of both a stop and a handling.

Commercial maritime carriers usually plan a sequence of port calls to take on and discharge cargo in the course of a single voyage. Radioactive materials packages that may be onboard would experience stop time at each such intermediate port, but measurable exposure would normally be limited to hold inspectors, and the latter are modeled under keyword HANDLING.

Inspection/Weigh Station stops are often associated with state and national boundary crossings. Trucks and railcars carrying radioactive materials may be required to stop at a state boundary for inspection. Exposure of inspectors located at short distances from the shipment should be modeled with the HANDLING subroutine, while exposure of weigh-station operators and other personnel located at greater distances from the shipment should be considered under the keyword STOP.